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ABSTRACT

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Problematizing Complex Datasets for Students: Design Principles for Inquiry Curriculum

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ABSTRACT

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Problematizing complex datasets for students: Design principles for inquiry curriculum

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Introduction: the design challenge of complex datasets

Recent advances in computer technologies, tele-communications, and learning sciences have resulted in a plethora of new tools for classroom inquiry. Tools such as data visualizers (e.g. Gordin & Pea, 1995), simulations (e.g. White & Frederiksen, 1995), and digital libraries and web browsers (e.g. Soloway, 1997) can bring unprecedented amounts of information directly to students and teachers in the classroom. While they represent exciting possibilities for teaching and learning through inquiry, there are many challenges involved in designing classroom activity around these sources of complex data.

Classroom inquiry projects which use complex datasets often have one of two problems: either (1) students use only a small, pre-determined subset of the available data, and so do not develop skills and habits for making sense of complexity, or (2) students become lost in the information they see, failing to learn domain concepts or "discovering" false ones. As curriculum designers, we need to develop effective design approaches for helping students learn to make sense of complexity, balancing the need for structure with opportunities for freer exploration.

In this paper we describe one product of our design research around this problem: the "Earth Structures and Processes" inquiry unit. This curriculum unit was developed by the authors and others as part of the Supportive Inquiry-Based Learning Environments project (Loh et al., 1997; Loh et al., 1998; Radinsky et al., 1998) at Northwestern University, in collaboration with the Center for Learning Technologies in Urban Schools. We have tried to create an inquiry curriculum that helps teachers give students extensive guidance and practice in developing "ways of seeing" that are helpful for understanding complex data about earth structures and processes. At the same time, we have tried to design activities so that students take on increasing amounts of responsibility for making meaning of large sets of data themselves. We have tried to build in the need for students to make their own observations, questions, and explanations about data, supporting explanations with observable evidence.

One key element in making sense of complexity is *reflection.* Our goal is to develop a set of curriculum design principles to help teachers and designers facilitate reflective inquiry with complex datasets. For the purposes of the design analysis presented here, we examine the kinds of reflection that were manifested in the enactment of the Earth Structures and Processes unit. We begin with a brief discussion to operationalize the construct of reflective inquiry. We then present an overview of the design of the curriculum unit. Next we discuss four design principles that emerged through the evolving design of the unit's activities, over several iterations of design and classroom enactment. We use these design principles as a framework for presenting examples of student discourse from the most recent enactment of the unit, to illustrate relationships between designed elements of the curriculum, and particular kinds of reflective activity demonstrated by students

What is reflective inquiry?

What do we mean by *reflective inquiry?* Hawkins, Mawby and Ghitman (1987) identify reflection as the key element of critical inquiry:

> Critical inquiry skills are close kin to what has been described as reflective thinking -- the ability to stand back from a topic or problem and reflect on it from a variety of perspectives... [This type of inquiry involves] active development of a question or problem, and exploration of information in order to find an answer or develop a connected, meaningful perspective... Previous assumptions are critically examined in the process. (p. 276)

Two of the central concepts here -- temporarily *stepping back* from ongoing work, and consideration from *multiple perspectives* -- also are features of Collins and Brown's (1988) discussion of ways that technology can promote learning through reflection on performances.

Another feature of reflective inquiry suggested by this passage is that of *active development of questions or problems.* Lehrer and Romberg (1996), and Hiebert et al (1996) have characterized types of reflective questions generated by students and teachers in conducting classroom inquiry, with a focus on reflection and the generation of valuable problems for investigation. In responses to this definition of reflection as *problematizing*, Smith (1997), Prawat (1997), and Hiebert et al (1997) suggest several aspects of inquiry activity that might be problematized in the classroom: for example, data points and representations, different possible problems within the situation, computational and problem-solving strategies, and students' own conceptions related to the domain as they understand it.

Also, the materials used in classroom activity can serve as another focus for reflection, as in the example of math manipulatives such as base 10 blocks (Fuson & Fraivillig, 1993). In this case, the materials are not to be considered problematic in their own right, but rather in their role as a *model* mediating between domain concepts (e.g. concepts of number) and items from experienced situations (e.g. cookies on a plate).

Others have characterized reflective inquiry in more explicitly cognitive terms. For instance, Klahr Dunbar and Fay (1990) distinguish between data-driven inquirers who explore the "experiment space," and more reflective inquirers who explore the "hypothesis space," stepping back from work with data to consider multiple hypotheses that might be ruled out, or tested strategically. Schauble, Raghavan and Glaser (1993) state that "the specific importance of reflection is its role in consolidating the development of new strategies," linking reflection with the self-regulatory skills of maintaining goal-orientation (i.e. "holding in mind the goals and sub-goals [of] scientific discovery"), and self-evaluation during experimentation.

The work presented here is part of a larger effort to develop a model of reflection in inquiry, in order to better understand the roles of reflection in teaching learning, and to be able to design inquiry curriculum which promotes reflection. Following the literature discussed above, we operationalize reflective inquiry as a mode of activity in which students:

- periodically step back from ongoing activity with data, and make connections with a second perspective on their understanding of their current task, such as
    - domain concepts;
    - prior experiences, in or out of class;
    - goals of the current activity; or
    - expected outcomes of the current activity; and
- generate questions, observations, predictions or explanations around artifacts of the inquiry process, such as:

- data points, such as dots on a map or numerical values in a list;
- real-world referents of data, such as mountains or earthquakes;
- models (physical or mental) representing relationships among data;
- problems or problem representations; or
- problem-solving strategies.

This characterization of reflection in inquiry has guided our study of student activity over several cycles of design and enactment of the Earth Structures and Processes unit. Each iteration of the unit enabled us to explore the role of particular designs in promoting particular types of reflection. Therefore we structure our discussion of the kinds of reflection that happened around our current design rationale for the unit.

Design of the curriculum

This unit was designed for a 6th or 7th grade class, to be conducting over 6 to 10 weeks. The unit covers content about the structure of the earth's crust, tectonic plate locations and movement, mechanisms of earthquakes and volcanoes, applying latitude and longitude, modeling earth structures and processes, map and globe reading, topography, and world geography. Data sources used in the unit include U.S. Geological Survey resources on the Internet, and the commercially available Geodynamics Database software.

1. STAGING ACTIVITIES

In skill-building and concept-building activities, students do mini-investigations of particular structures on the earth; create models of earth structures from topographical maps; and study and enact myths as explanations of earth structures. Map-making, plotting, and map usage teach concepts of graphic representations of data, for both continuous values (elevation) and point data (earthquake magnitude and depth). These staging activities introduce domain concepts both from the abstract and from the particular.

Staging activities give students a chance to develop expertise through specific "case studies" of formations in the earth's crust, examined through different points of view. For example:

1.1 Earth structure expert groups

Detailed information about 10 specific structures on the earth's crust is brought into the classroom through student "expert groups." Each group studies an information sheet about their earth structure (see Figure 1), and teachers can extend this research with suggested Internet or library resources if desired.

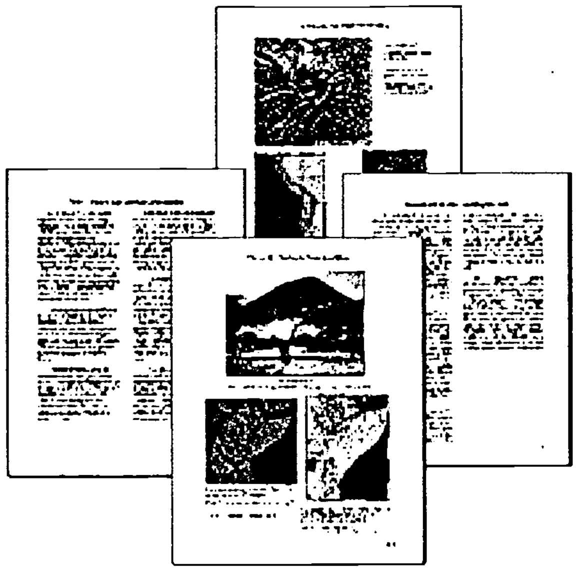

Figure 1. Earth structure information sheets.

1.2 Modeling topographic data

Observations and questions for inquiry are generated by creating and discussing 3D models of topographic maps of earth structures (see Figure 2). Making these models gives students a chance to interpret a dataset by creating another representation of it. The models also are meant to provide artifacts for later reflection, as students construct explanations of earth structures using their evolving domain understanding.

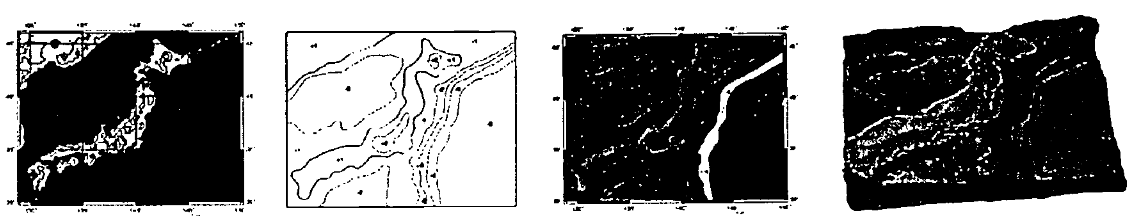

Figure 2. Topographic maps and model of Japan

2. INQUIRY CYCLES

After a series of such staging activities, students begin cycles of inquiry in which they analyze earthquake and volcano data from a variety of sources. These investigations are interspersed with lectures and readings in preparation for the investigations; whole class and small group discussion activities to explore concepts and understandings; and hands-on activities to build plotting and modeling skills.

The first inquiry cycle involves gathering current earthquake data from the Internet and plotting it on a world map, to observe locations and measurements of tectonic activity and generate questions. In the second inquiry cycle students use a full year's earthquake data set to predict plate boundaries around the globe; students use a transparency overlay to draw their predictions, and use a "jigsaw" lesson structure and additional data to check their predictions. The third inquiry cycle uses the discovered plate boundaries, along with volcano and topographic data, to predict directions of plate motion; students create clay models representing plates, prominent earth structures, and plate motion. The complex data visualizations available in the Geodynamics Database software are used during the last two inquiry cycles.

Inquiry cycles involve four kinds of activity:

2.1 Creating datasets and looking for patterns

Students create their own datasets initially by plotting the most recent earthquakes from the Internet (see Figure 3). This is extended by dividing up the world into regions; groups monitor and plot earthquake activity in their region for a period of time. In this way a large dataset is assembled by the class as a whole, which is then studied for patterns in the data.

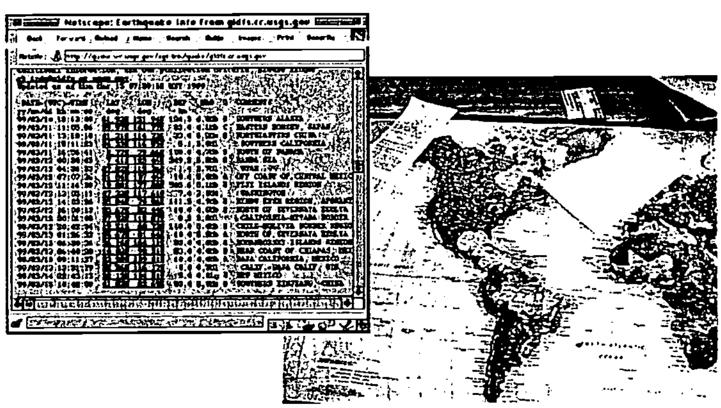

Figure 3. Earthquake data gathered and plotted by students.

2.2 Making predictions from a large dataset

After seeding discussions with the class-created datasets, a larger pre-designed dataset is introduced. Students draw predictions of plate boundaries on a plastic map overlay, using a data map showing one year's dataset of large earthquakes worldwide (see Figure 4).

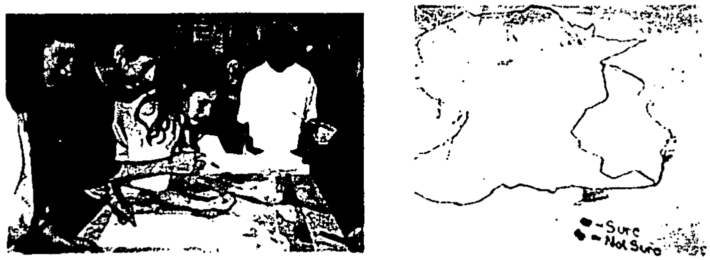

Figure 4. Students marking boundaries that they are "Sure" of in one color, and "Not Sure" in another.

2.3 Refining predictions with more data

After using one large dataset for making concrete predictions, students are taught how to query much larger, interactive data sources. Students use Geodynamics Database software and other data sources to refine all groups' predictions of plate boundaries, investigating the areas that were argued over in the previous phase of inquiry, and areas where predictions were less certain.

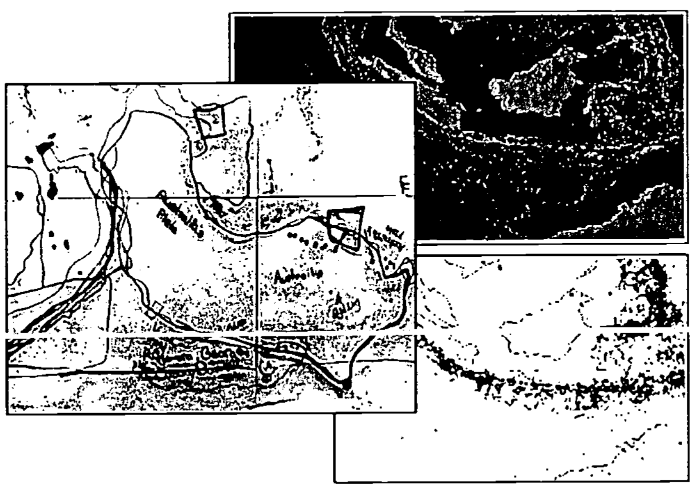

Figure 5. A plastic map overlay showing students' revised predictions, alongside screens from the data visualization software.

2.4 Representing findings leads to new questions

The refined predictions from phase 2.3 generate new, more sophisticated directions for students' investigations. Models and images showing students' plate boundary predictions and data interpretations are used to generate new questions about the directions of plate motion, requiring further data and another inquiry cycle.

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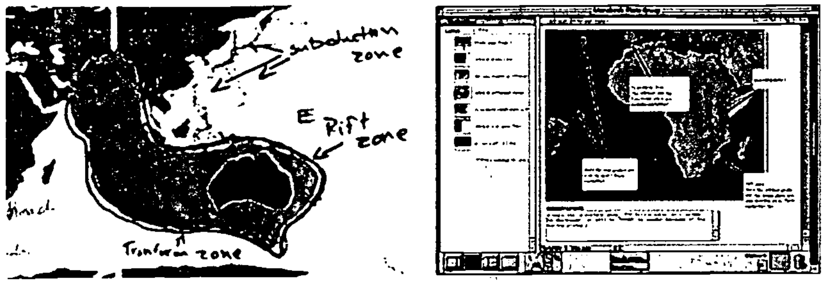

Figure 6. Students' clay model of their plate, with a computer screen showing questions and observations about plate boundaries related to earthquake and volcano data.

3. PRESENTATION OF FINDINGS

Students create presentations and/or other instructional activities for a younger class, using the artifacts created in the unit to explain their understandings of earth structures and processes, and also summarizing their inquiry activities to show how they developed these understandings.

There are two kinds of presentations that students do during the unit:

3.1 Presentations during inquiry

Groups compare their interpretations and findings with those of other groups (see Figure 7), and identify areas that need more work. These presentations lead to further investigations with data, ad groups questions become more focused and refined around needing to understand particular phenomena.

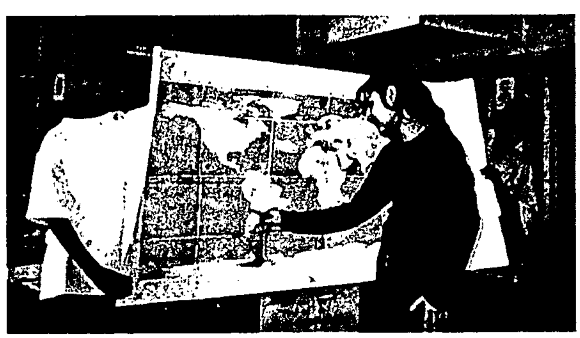

Figure 7. Students present their plate boundary predictions to another group as part of a "mini-conference."

3.2 Final presentations

Groups use the artifacts that they have created (both computer-based and physical artifacts) to teach younger students about earth's crustal structures and processes of change (see Figure 8). They explain their own learning process, as well as the domain concepts they have come to understand.

Figure 8. Students teach a group from a younger class about plate tectonics, using the artifacts of their inquiry (computer files and physical models).

Design principles: Connecting designs to reflection

The design principles proposed in this section have been emergent in our design work, and embody our working hypotheses about how curriculum designs can impact reflection in inquiry. We are currently developing a more complete framework for analyzing episodes of reflection in inquiry, to be presented elsewhere. The discussion here is to highlight points of connection between students' reflective comments, and the curriculum designs which were intended to prompt such reflections.

We use four emergent design principles to structure our presentation of the kinds of reflection that did occur in the course of enactment. The four principles are:

- Cultivate the need for data
- Introduce data through students' work
- Promote debate with evidence
- Build inquiry on earlier artifacts

Below we explore each of these principles as they played out in the design rationale and enactment of the unit.

1. Cultivating the need for data

Students need to *need* the data, or they will not reflect on its meaning. By creating their own datasets to generate new questions for them, students approach other complex datasets with a need to understand. This can lead them to develop their own high standards for quality work, as well as provide insights into what the complex data represent.

To problematize the large sets of earthquake data, reflective discussions were used between the phases of the inquiry cycle described above. These discussions connected the questions and observations from one phase to the investigations of the next. For example, as students were introduced to the data available on the Internet, the teacher brought out a wide range of reflections about the data they saw, encouraging students to problematize the individual data points (all student names are pseudonyms):

> Jonah: Can we have earthquakes in water?
>
> Anna: Ms. Mundt, why is there more earthquakes in the morning?

These kinds of questions were revisited after the first datasets were created through student plotting of downloaded data. In the discussion between inquiry phases 2.1 and 2.2, ideas were brought out that problematized *patterns* of data, seeking connections to possible explanations for the patterns:

> Anna: I think maybe all the earthquakes are connected
>
> Arthur: [And there would be] aftershocks in Nigeria
>
> Renee: You could make a graph of this! [earthquake data]
>
> Lanie: If we looked at 2 years ago, then last year's, then this year's ...
>
> Renee: If we looked in the computer where the first earthquake was, when the date was...

In these discussions, patterns are made problematic, setting the stage for looking for patterns in the larger dataset used in inquiry phase 2.3. Thus the problematizing done here sets the stage for later reflection back to these concepts from discussion.

2. Introducing data through students' work

Rather than the teacher and the text being gatekeepers of all information, important data is brought into the classroom through the artifacts created by students. This can promote an environment in which students pay close attention to what one another are saying, and can relieve some of the burden on teachers to have to provide all of the relevant domain information.

The unit provides lots of domain information within the materials used in the lessons themselves (in addition to pointers for further teacher learning in other places). For example, through the "Information Sheets" describing a range of real earth structures, concrete domain facts are brought directly to the student "expert groups" for mini-research projects early in the unit. This means the teacher AND the other students can learn important information from their fellow classmates, as key concepts are introduced into classroom discussions through the students' presentations.

To make this kind of introduction of information effective, students must learn to reflect back on comments made by their classmates. This kind of referencing of each other did occur in the enactments. For example, certain pieces of information brought out in presentations of the earth structure expert groups were repeatedly mentioned later in the unit:

> Lanie: I remember when Bobby said the Himalayas were growing something like 3 cm per year ... Maybe that's how fast the plates are moving
>
> Mohammad: If it grows 3 cm per year ... it will be bigger than the earth!

Here we see one reflection which references an earlier experience (Bobby's group's presentation) to make sense of a current question (how fast plates move); and another reflection which problematizes the information presented by Bobby's group.

Also, students introduced another kind of information for each other: feedback on their evolving interpretations of data. This was accomplished through the mini-conferences that connected phases 2.2 – 2.4 of the inquiry cycle. This creates a more student-referenced environment than receiving feedback only from the teacher. It produced reflections on each others' interpretations such as the following:

> Gerald: We thought that [putting a boundary] here ... was the most accurate ... but then with Taniesha's group ... we found that there was a crack ... We proved that by looking at the computer data
>
> Bobby: For some earth structures ... you could have a subduction zone ... then right next to it a transform zone
>
> Gerald: [We found] many buckling zones ... and no transform zones at all

This design approach provides the teacher with tools for making students' work relevant to the larger goals of the classroom inquiry. This usefulness of the information they produce seems helpful in promoting reflection, in the form of connecting current activity with prior classroom experiences, including recurring discussions of domain concepts and student predictions and interpretations.

3. Promoting debate with evidence

Norms of classroom discussion and "table talk" during project work can be developed by the teacher, and supported by activities that distinguish between *observations* and *explanations* (see Kuhn, 1989, 1993, for theoretical discussions of these dispositions and skills). Assessment of *observation habits* rather than just correct answers, and activities that include repeated cycles of predictions and revisions, can help promote these norms.

The unit uses "jigsaw" cooperative group structures to divide up places on earth which students will study, in several different phases of the unit. By having to match their predictions from one place with another group's predictions from another, students are led to use the data as a basis for trying to improve their predictions so that all groups agree. Also, reflection questions for each activity point to the need to explain how assumptions are supported by evidence.

Norms of teacher-facilitated discussion can promote argument from evidence rather than authority. These include encouraging students to explain and challenge ideas based on shared observations of data:

Anna:	Maybe [earthquakes] has to do with the water …
Renee:	California's dry, and it has earthquakes
Ahad:	That's because it's a tropical area
Mohammad:	I thought earthquakes happen … whenever there's coasts
Renee:	Well Florida has an ocean by it, and there's no earthquakes

Here Renee uses observable evidence to challenge her classmates' explanations – a reflective act that connects concepts from discussion with explanatory domain models. By allowing these debates to proceed, instead of inserting the "correct" answers, the teacher uses the unit's activities as a prompt to get students in the habit of connecting evidence to their explanations. When the teacher does intervene in a debate, it is to ask students to be more explicit in their observations or explanations:

Arthur:	Some of these earthquakes are related to each other … they're only 2 minutes apart
Lanie:	There are patterns … it happens in clusters or groups … not many happen alone by themselves
Teacher:	*Why do they come in clusters?*
Lanie:	… aftershocks
Taniesha:	[if there are aftershocks after an earthquake], so when does it stop?

The design of the unit's activities requires teachers to push students to develop and defend their own interpretations. Open-ended interpretation tasks, like explaining the formation of an earth structure, or predicting the boundaries of a plate, can promote the kinds of challenges raised by Renee and Taniesha above. However, we found that they are much more effective when the debates actually lead somewhere, such as debating plate boundaries before creating models of the plates based on those boundaries. The need for supporting evidence must be reinforced by the teacher throughout the unit. Otherwise, students will focus on who has the right answer, and will reason from authority rather than evidence.

4. Building inquiry on earlier artifacts

In order to reflect, students need artifacts to reflect back on -- artifacts which capture their thinking and understandings. Inquiry cycles and presentations are sequenced so that students create artifacts in one activity which they will use as data in later activities. For example, after mapping separate plates, they create a world plate map as a whole class; this world plate map is the starting point for investigating directions of plate motion in the next inquiry cycle. Similarly, the models and data representations they create in each phase of the unit can be used to explain the domain concepts to an audience of younger students in the culminating activity.

Reflecting back on their earlier artifacts was something that happened periodically during enactments, as when Bobby recalled his clay model during a discussion of plates:

> Bobby: Say for Japan, where there's more depth than altitude, it might be that two plates collided, and they went down - and that's how we got more depth.

We had hoped for more of these kinds of direct reflections connecting artifacts to understandings. Our current re-design of the unit has focused on developing the trajectory of student products to better support this kind of reflection. For example, groups will create all of their artifacts around the same earth structure, rather than skipping around to different areas. We hope that this will help them develop more of a coherent set of connections among the different types of data and models that they produce.

In this sense, a clear trajectory of artifacts is closely related to what teachers described as a better "flow" to the unit – a sense of building from one activity to the next. If this flow of activities is supported by a coherent trajectory of increasingly-complex artifacts created by students, we hope to see increased reflections on these artifacts. We expect that this will also motivate students to focus more on the quality of their artifacts (if they must use them later), and will help build an environment in which revision is the norm.

Future directions

These four design principles, and hypothesized connections to reflective student discourse, indicate the future directions of our program of design research. By making our assumptions explicit, and searching for mappings between design assumptions and reflection in activity, we hope to begin a detailed investigation of the role of particular design elements in fostering reflective classroom inquiry.

A closer analysis of the trajectories of change in reflective discourse for particular students will give us more feedback on the actual impact of the designs. In analysis of reflective episodes around each of the major activities of the unit, we will look for evidence of the ways students refer to particular artifacts in reflections connecting one activity context with another. We expect that different students have different dispositions for reflection at the outset, and thus will change along different trajectories.

The concept of students' dispositions for reflective inquiry is closely tied to Rogoff's (1995) concept of roles for participation in group activity. One of our larger goals with this analysis will be to begin mapping out different trajectories of change as students adopt new roles in their group work, with respect to activity around complex data. By starting from our design rationale, and mapping our assumptions to actual roles adopted by students, we look for connections between particular design approaches, and particular changes in the disposition to reflect. We feel that this approach has great promise for making sense of the complex terrain that is the design of curriculum.

Earth Structures and Processes: Exploring the earth's crust with models and data

http://www.letus.nwu.edu/projects/esp/esp.html

A thematic science unit from the Center for Learning Technologies in Urban Schools

Northwestern University: Josh Radinsky, Ben Loh, Sue Marshall – SIBLE Project

Chicago Public Schools: Jennifer Mundt – Boone Elementary, SIBLE Project

Judith Lachance-Whitcomb – Sauganash Elementary

Lou Ellen Finn, Thea Raedeke – Hayt Elementary

Jean Bramlette – Haines Elementary

Sonia Flore, Kathleen North-Tomczyk – Saucedo Academy

Jennifer Olson – Inter-American Magnet School

The central "seed" activity for this unit was designed by Ben Loh for the SIBLE project <http://www.ls.sesp.nwu.edu/sible/>. It was later adapted and conducted with a 7th grade class over 2 weeks by Jennifer Mundt (Boone Elementary, CPS), Ben Loh, and Josh Radinsky. Some initial materials and lesson plans were generated in the course of this enactment.

The following semester this seed activity was brought to a work circle of teachers from two schools, including Jean Bramlette (Haines Elementary, CPS), Sonia Flores (Saucedo Academy, CPS), Kathleen North-Tomczyk (Saucedo Academy, CPS), working with Josh Radinsky. A variety of staging activities were drafted by this group, and conducted with students from an after-school club in one school, and a 7th grade class in the other. Work circle members alternated teaching the activities and observing one another, later reflecting on how to revise and write up each activity. Drafts of a unit outline and specific activities were presented to meetings of science teachers from 6th, 7th and 8th grades at eachwork circle school for feedback.

Building on these mini-enactments and revisions, the complete unit materials were then written and revised by Jennifer Mundt, Josh Radinsky, Judith Lachance-Whitcomb (Sauganash Elementary, CPS) and LouEllen Finn (Hayt Elementary, CPS) over the summer. This completed draft of a 6 – 8 week unit was piloted in about 10 classrooms during the school year, and studied in depth in three classrooms by Josh Radinsky working with Jennifer Mundt, Jennifer Olson (Inter-American Magnet, CPS), and Thea Raedeke (Hayt Elementary, CPS).

These pilot studies led to extensive revisions of the unit, and culminated in a unit-revision meeting to compile ideas for improving the content, structure, and flow of the unit. The revised unit will be available for the 1999-2000 academic year.

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